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FINAL REPORT

OF THE

NEUTRON SENSITIVITY OF A GEIGER COUNTER

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The sensitivity to neutrons of a Far-West GM-1 Geiger counter was measured by finding its response in a radiation field dominated by neutrons. The sensitivty to neutrons is only about 0.3 percent of its response to gamma rays.

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Neutron Sensitivity of a Geiger Counter
Craig R. Heimbach

1. INTRODUCTION

In radiation dosimetry, it is desirable to separate neutron from gamma-ray exposure. This is often difficult because neutron detectors are sensitive to gamma rays and gamma detectors are sensitive to neutrons.

The Aberdeen Pulse Radiation Facility (APRF) has developed radiation fields which are dominated by neutrons. Measuring the small gamma-ray components of these fields is difficult because of the neutron sensitivity of the detectors used to measure the gamma rays.

A previous investigation (1) examined the use of Thermoluminescent Detectors (TLDs) for this purpose. Results were sufficient for some purposes, but an examination of the literature (2,3,4,5) revealed that Geiger counters might have a smaller sensitivity to neutrons. Two Far-West (FW) GM-1 type Geiger counters were acquired for evaluation and use in mixed neutron/gamma radiation fields.

2. GAMMA-RAY SENSITIVITY

Before the neutron sensitivity of a Geiger counter can be investigated, the gamma-ray sensitivity of the instrument must be determined. Most of the response in radiation fields will be due to gamma rays.

Figure 1 shows the relative gamma-ray response of the GM-1 as supplied by the manufacturer's operating notes. The sensitivity at the low end is flattened by the counter wall material, consisting of 90 mg/cm^2 Fe, 807 mg/cm^2 Pb, 200 mg/cm^2 Al, and 480 mg/cm^2 of ^{6}LiF. The manufacturer gave no results above 2 MeV.

For many purposes, knowing the response up to 2 MeV is sufficient. In some environments at APRF, gamma-rays up to 10 MeV are encountered. Therefore, the sensitivity curve was extended past 10 MeV by using responses determined by others (6 and 7). A composite curve is given in Figure 2. The lines are normalized to agree at 1 MeV. The solid line (from the manufacturer) is used below 1 MeV and the dotted line above 1 MeV.

Both Geiger counters were calibrated at APPF using a Cs-137 gamma-ray source. The calibration constants as determined by the manufacturer, also using Cs-137, and by APRF are listed in Table 1. Agreement is good. The APRF values will be used.

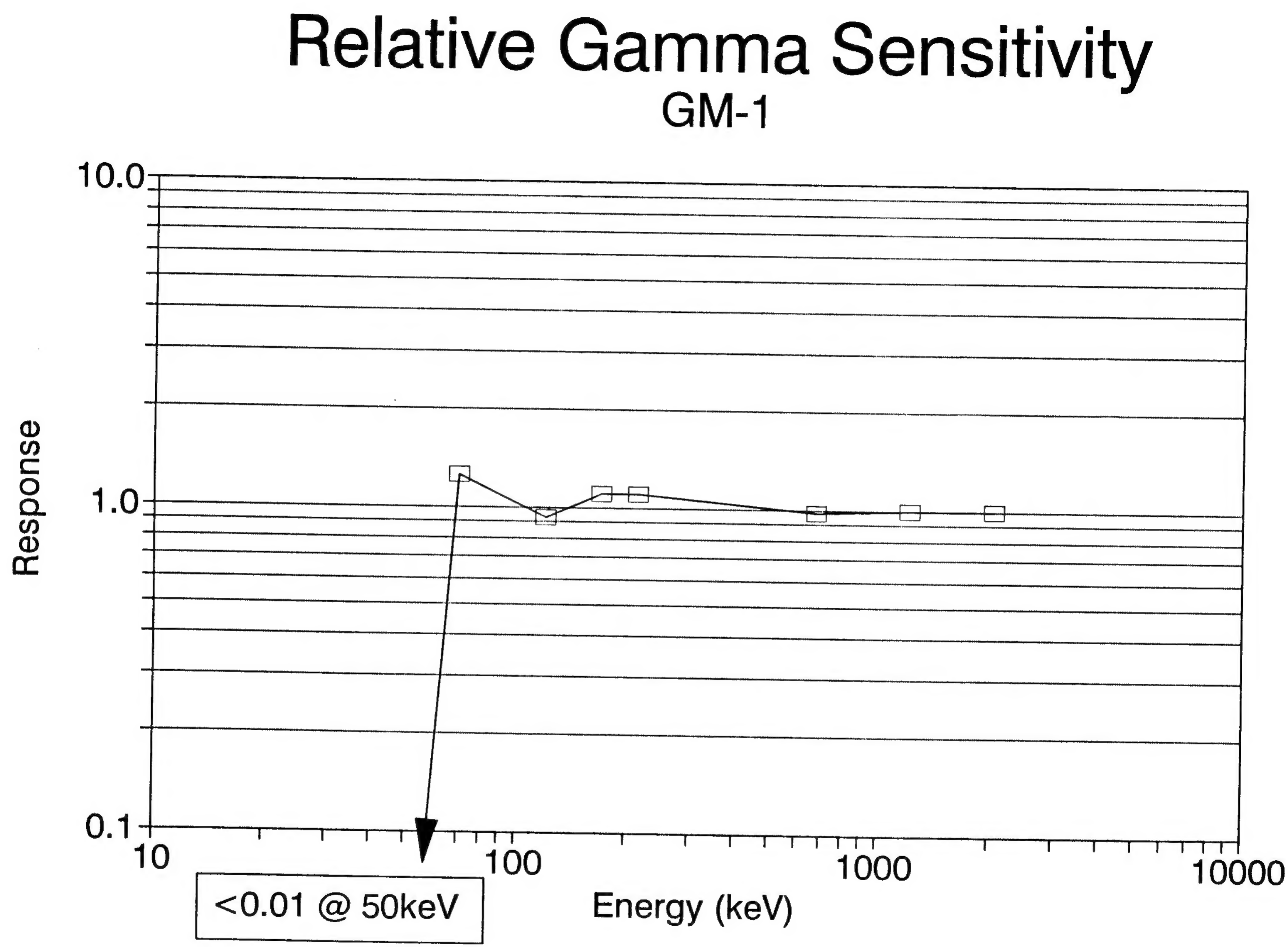

Figure 1. Relative gamma sensitivity of Far-West GM-1, 0 to 2 MeV.

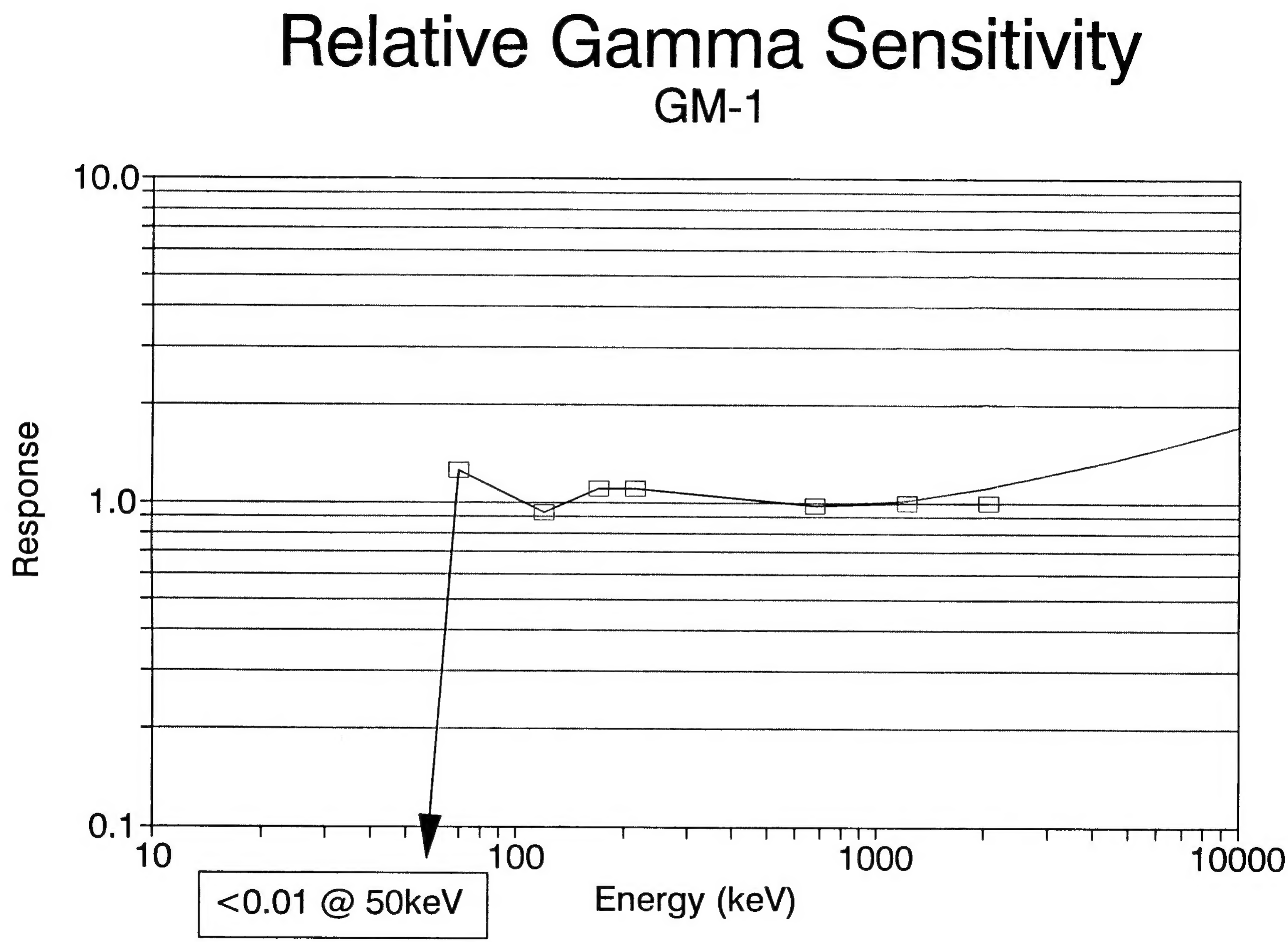

Figure 2. Relative gamma sensitivity of Far-West GM-1, 0 to 10 MeV.

TABLE 1. GM CALIBRATION FOR Cs-137

Detector	Far West	APRF	Ratio
	(Rad(Ti)/count)		(APRF/FW)
GM-533	5.67×10^{-7}	5.78×10^{-7}	1.02
GM-536	6.22×10^{-7}	6.47×10^{-7}	1.04

3. NEUTRON SENSITIVITY

A technique developed (8) for measuring neutron sensitivity of gamma-ray detectors uses a lead sphere surrounding a Cf-252 source to produce a radiation field dominated by neutrons. The response of a detector is measured, the gamma-ray response is subtracted out, and the remainder of the response is attributed to neutrons. For this technique to work, it is essential that a substantial fraction of the detector response be due to neutrons. This technique was followed in Reference 1 for TLDs, and was applied here for the Far-West Geiger counters.

A diagram of the system is shown in Figure 3. The distance from the center of the sphere to the detectors was 238.5 mm, slightly closer than previous measurements. Otherwise, the geometry was identical.

ANISN was used with DABL 69 group cross sections to calculate the neutron and gamma-ray environments at the test location. ANISN was run forward, with spherical geometry, S16. The spectra are shown in Figures 4 and 5, and listed in Tables 2 and 3.

The dose results from Tables 2 and 3 are summarized in Table 4, and compared with a previous calculation from Reference 8. The values in Table 4 from Reference 8 have been adjusted for distance (from 248.5 to 238.5 mm, a factor of 1.08), and for conversion of Rad(Air) to Rad(Ti) (0.91).

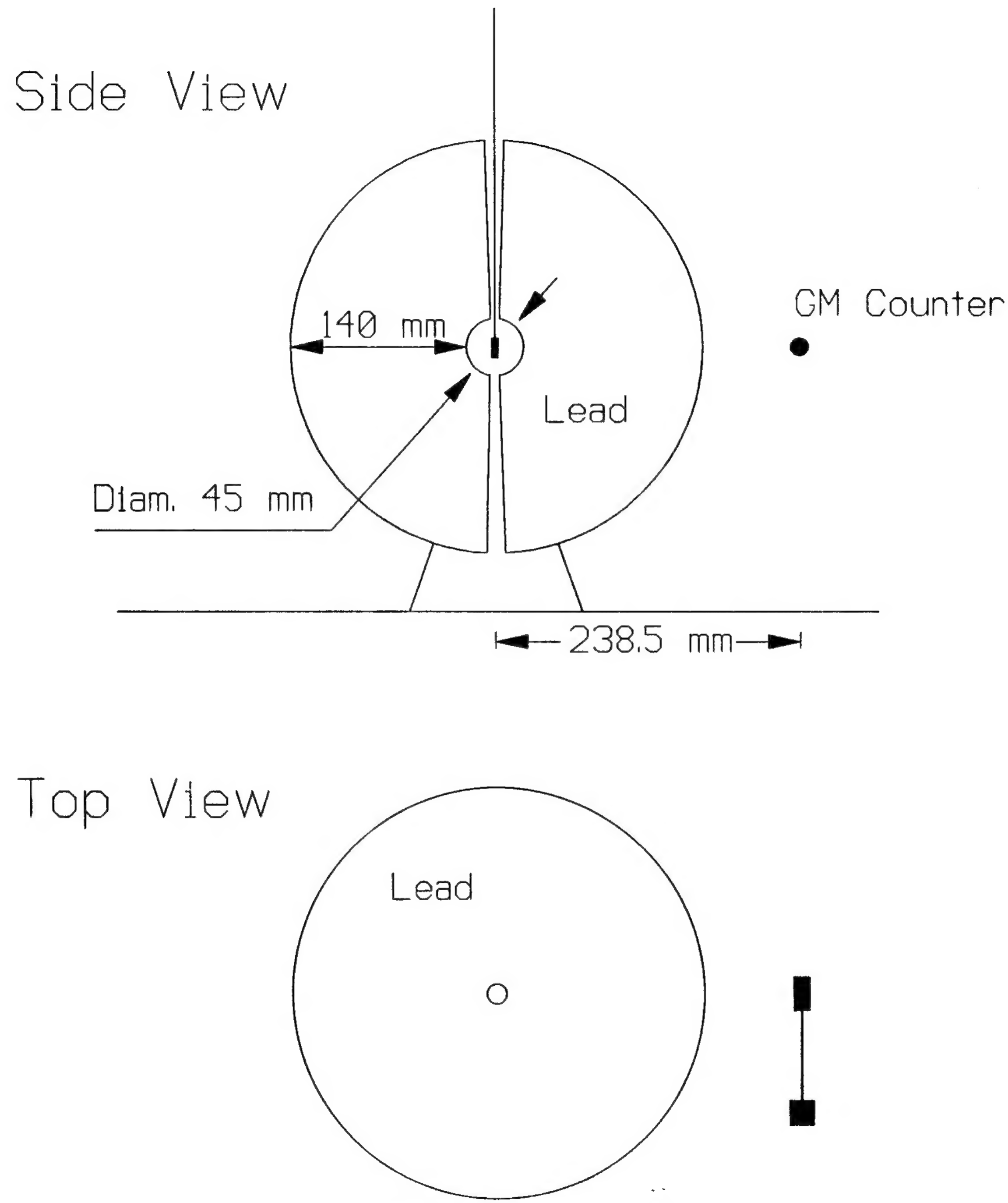

Figure 3. GM calibration using lead sphere surrounding a Cf-252 source.

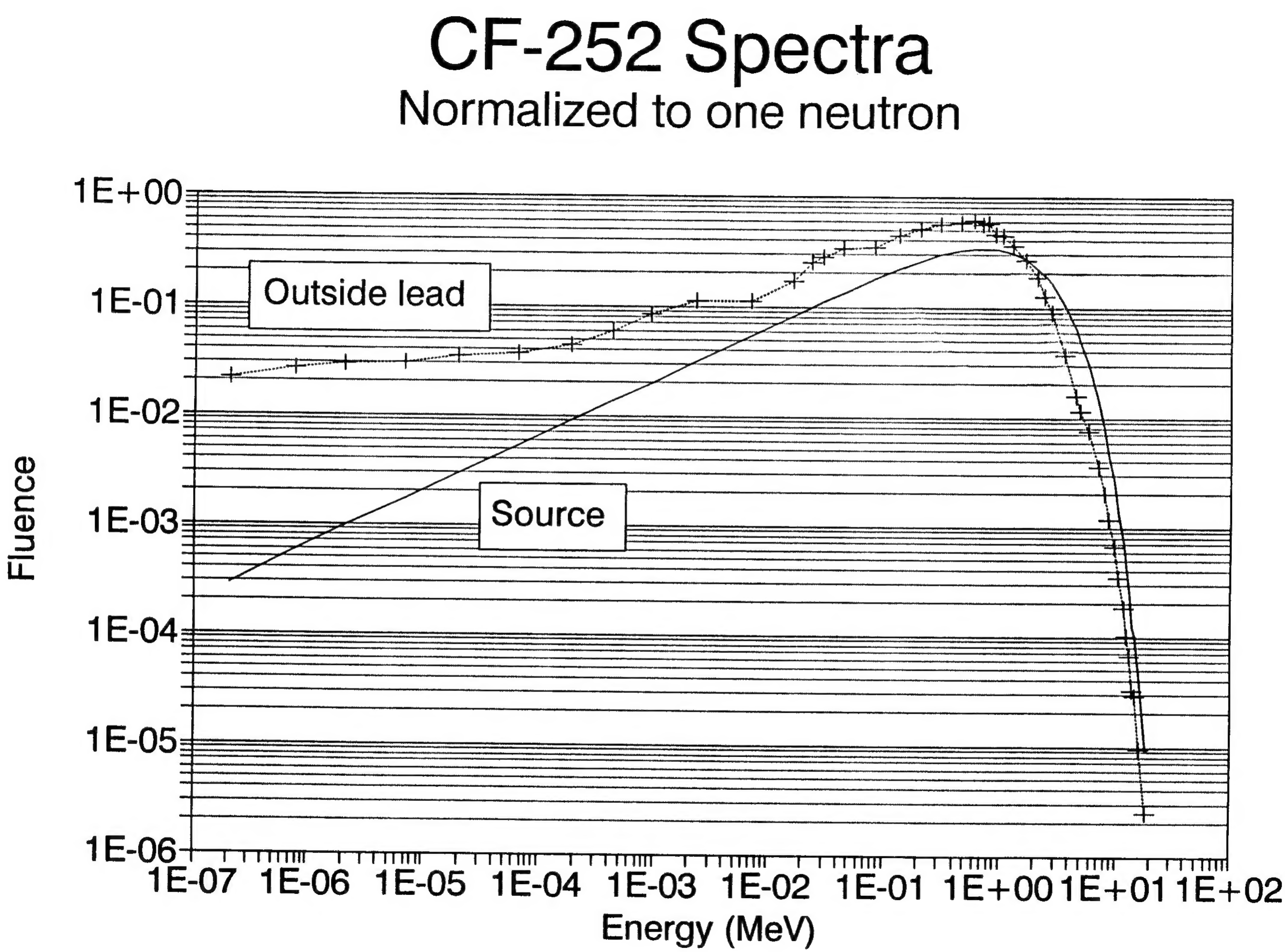

Figure 4. Source and calculated Cf-252 spectra.

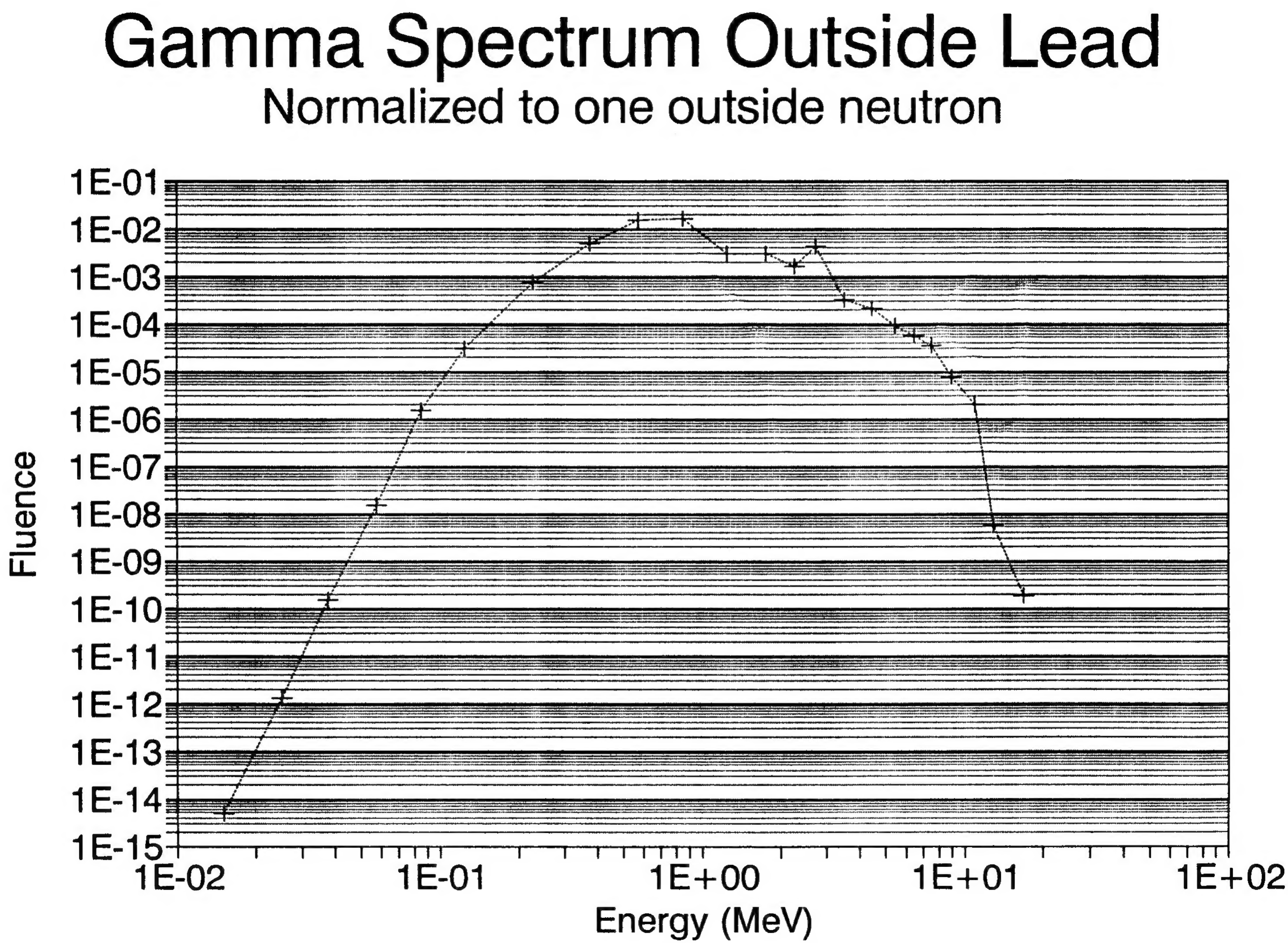

Figure 5. Calculated gamma-ray spectrum.

TABLE 2. SOURCE AND CALCULATED NEUTRON SPECTRA

Energy (MeV)	Source Neutrons (Group Fluence)	Outside Neutrons (Group Fluence)	Tissue Response Rad(Ti)/n/cm^2
19.60	2.50e-05	1.03e-09	7.36e-09
16.90	8.26e-05	2.99e-09	6.94e-09
14.90	7.03e-05	3.10e-09	6.68e-09
14.20	4.08e-05	2.04e-09	6.56e-09
13.80	0.000323	1.33e-08	6.37e-09
12.50	0.000126	4.63e-09	6.12e-09
12.20	0.000785	3.16e-08	6.07e-09
11.10	0.001459	5.83e-08	5.73e-09
10.00	0.002521	9.94e-08	5.51e-09
9.05	0.004077	1.58e-07	5.23e-09
8.19	0.006212	2.45e-07	5.11e-09
7.41	0.014670	5.73e-07	4.95e-09
6.38	0.043272	1.64e-06	4.62e-09
4.97	0.011892	4.23e-07	4.38e-09
4.72	0.042350	1.61e-06	4.31e-09
4.07	0.111511	5.90e-06	4.07e-09
3.01	0.103258	8.71e-06	3.44e-09
2.39	0.015353	1.49e-06	3.15e-09
2.31	0.107405	1.35e-05	3.11e-09
1.83	0.109081	1.64e-05	2.68e-09
1.42	0.096346	1.74e-05	2.68e-09
1.11	0.047629	9.91e-06	2.05e-09
0.9616	0.047000	9.87e-06	2.05e-09
0.8209	0.026378	6.97e-06	2.05e-09
0.7427	0.034986	8.96e-06	2.05e-09
0.6393	0.029884	8.39e-06	2.05e-09
0.5502	0.058646	1.63e-05	1.27e-09
0.3688	0.035807	1.04e-05	1.27e-09
0.2472	0.023018	7.00e-06	1.27e-09
0.1576	0.010234	3.17e-06	7.80e-10
0.1111	0.010376	3.17e-06	5.44e-10
0.05248	0.002418	9.48e-07	3.06e-10

TABLE 2 (CONT'D)

Energy (MeV)	Source Neutrons (Group Fluence)	Outside Neutrons (Group Fluence)	Tissue Response Rad(Ti)/n/cm^2
0.03431	0.001056	4.09e-07	3.06e-10
0.02479	0.000289	1.13e-07	2.08e-10
0.02188	0.000950	2.97e-07	1.43e-10
0.01033	0.000375	1.21e-07	6.11e-11
3.36e-03	6.63e-05	3.64e-08	2.16e-11
1.23e-03	1.29e-05	8.45e-09	9.02e-12
5.83e-04	4.18e-06	2.82e-09	3.12e-12
2.75e-04	1.56e-06	1.18e-09	3.12e-12
1.01e-04	3.80e-07	4.12e-10	1.21e-12
2.90e-05	5.35e-08	9.91e-11	1.26e-12
1.07e-05	1.30e-08	3.50e-11	1.96e-12
3.06e-06	1.83e-09	8.72e-12	3.32e-12
1.13e-06	4.08e-10	2.90e-12	5.44e-12
4.14e-07	1.17e-10	1.35e-12	2.24e-11
1.00e-10			
Fluence	1.000	0.0001544	
Rad (Ti)	2.879e-09	3.518e-13	

TABLE 3. SOURCE AND CALCULATED GAMMA-RAY SPECTRA (GAMMA-RAY SOURCE NORMALIZED FOR CORRECT NEUTRON-TO-GAMMA DOSE RATIO)

Energy (MeV)	Source Gammas (Group Fluence)	Direct Gammas (Group Fluence)	Secondary Gammas (Group Fluence)	Total Gammas (Group Fluence)	Tissue Response Rad(Ti)/n/cm^2
20.00	2.07e-07	5.17e-16	1.69e-13	1.70e-13	3.55e-09
14.00	2.12e-06	1.37e-14	1.73e-12	1.74e-12	3.15e-09
12.00	2.03e-05	2.34e-13	6.05e-10	6.05e-10	2.75e-09
10.00	1.94e-04	4.11e-12	2.28e-09	2.28e-09	2.35e-09
8.00	4.55e-04	1.50e-11	5.27e-09	5.29e-09	2.03e-09
7.00	0.00141	6.48e-11	8.36e-09	8.42e-09	1.87e-09
6.00	0.00436	2.77e-10	1.36e-08	1.39e-08	1.65e-09
5.00	0.01350	1.19e-09	3.14e-08	3.26e-08	1.43e-09
4.00	0.04177	4.96e-09	4.91e-08	5.41e-08	1.22e-09
3.00	0.04687	6.31e-09	3.16e-07	3.22e-07	1.03e-09
2.50	0.08247	1.17e-08	1.23e-07	1.35e-07	9.05e-09
2.00	0.14508	1.87e-08	2.32e-07	2.51e-07	7.57e-10
1.50	0.25526	2.24e-08	2.33e-07	2.55e-07	5.88e-10
1.00	0.23864	1.06e-08	7.49e-07	7.60e-07	4.28e-10
0.70	0.27086	7.53e-09	5.61e-07	5.69e-07	3.02e-10
0.45	0.20336	1.41e-09	1.09e-07	1.10e-07	1.95e-10
0.30	0.24092	1.63e-10	1.70e-08	1.72e-08	1.09e-10
0.15	0.08982	2.03e-12	2.21e-10	2.23e-10	5.31e-11
0.10	0.04840	3.84e-13	6.98e-12	7.36e-12	3.47e-11
0.07	0.02973	3.95e-15	5.77e-14	6.16e-14	3.17e-11
0.05	0.02011	1.66e-17	3.41e-16	3.58e-16	4.96e-11
0.03	0.02034	6.59e-20	1.92e-18	1.99e-18	1.14e-10
0.02	0.05642	2.30e-22	7.31e-21	7.54e-21	3.66e-10
0.01					
Fluence	1.81	8.531e-08	2.451e-06	2.536e-06	
Rad (Ti)	1.417e-09	2.551e-16	2.426e-15	2.581e-15	

TABLE 4. CALCULATED NEUTRON AND GAMMA DOSES

Cover	Source Type	Neutron Dose (Rad(Ti)/Source)	Gamma Dose (Rad(Ti)/Source)	Φ_N (>100 keV)
Lead	N only	3.52×10^{-13}	2.43×10^{-15}	0.000152
	G only	0	8.57×10^{-17}	0
No lead	N only	4.11×10^{-13}	4.27×10^{-17}	0.000140
	G only	0	1.14×10^{-13}	0
Lead	Mixed	3.52×10^{-13}	2.58×10^{-15}	0.000152
Lead (ref 8)	Mixed	-	9.34×10^{-16}	0.000153

Calculations for Table 4 were performed separately for neutron and gamma-ray sources. All the "N only" and "G only" results in Tables 2 and 3 are for one source particle. The APRF calculation of the Cf-252 mixed field was taken to have a neutron-to-gamma tissue dose ratio of 2.0. The APRF calculated values show substantially more gamma rays than Reference 8. The reason for this difference is not known. The neutron fluence results were confirmed with fission-chamber measurements, but there was no experimental verification of gamma-ray results.

The results of the Geiger counter measurements are listed in Table 5. The Cf-252 source strength was 1.655×10^9 n/s. The two sets of measurements for the first detector resulted from an attempt to ensure that the source was in the correct location. All counts were for 300 seconds and a background of 9.5 counts for 300 seconds was subtracted.

The last measurement listed, W3888', had a borated polyethylene brick placed between the lead sphere and the detector. The intent was to observe a decrease in the count rate due to a decrease in the neutron fluence. An increase in the count rate was actually observed. This resulted from an increase in secondary gamma production.

The neutron sensitivity calculations are given in Table 6. The measured gamma-ray calibration factors were adjusted down by 1.068, since the detectors will give more counts/rad because of the gamma-ray spectrum. The small residuals indicate that a field with an even higher neutron/gamma ratio would be more suitable for calibration of the Geiger counters.

TABLE 5. GEIGER COUNTER RAW DATA

Counter	Counts	Net c/s	Average
W3887	3475	11.55	
(GM-533)	3357	11.16	
	3395	11.28	11.33
W3887	3446	11.45	
(GM-533)	3448	11.46	
	3477	11.56	
	3270	10.87	
	3509	11.66	
	3320	11.03	11.34
W3888	3152	10.47	
(GM-536)	3242	10.77	
	3173	10.54	
	3106	10.32	
	3232	10.74	
	3276	10.89	10.62
W3888'	7805	25.98	25.98

TABLE 6. CALCULATIONS OF RELATIVE NEUTRON SENSITIVITY OF A GEIGER COUNTER

	Measured, μR/s	Calculated Gamma, μR/s	Residual, μR/s	Neutron, μR/s	Relative Neutron Response
GM-533	6.01	4.27	1.74	582	0.0030
GM-536	6.18	4.27	1.91	582	0.0033

The relative neutron response as found here is plotted versus other work in Figure 6. The energy used to plot the results of this test is the kerma-weighted average energy of 1.75 MeV. The average neutron energy was 1.3 MeV. It should be noted that only Reference 5 had a Geiger counter of the same type as here.

The response observed here, 0.3 percent, is consistent with that measured for other Geiger counters using alternate measurement techniques. Other values tend to be slightly lower.

Due to the uncertainty in the calculated gamma-ray environment, the small residual used to determine the neutron response, and the fact that this environment was not experimentally verified, a large uncertainty must be given to the neutron response. Based on this measurement, a value of 0.003 $\pm$ 0.001 will be used for the relative neutron response. This would give an uncertainty of 15 percent in the measured gamma dose in a field with a neutron/gamma tissue dose ratio of 100.

If the neutron spectrum differs substantially from the neutron spectrum outside the lead sphere, Figure 6 may be used as a guide for the correct response.

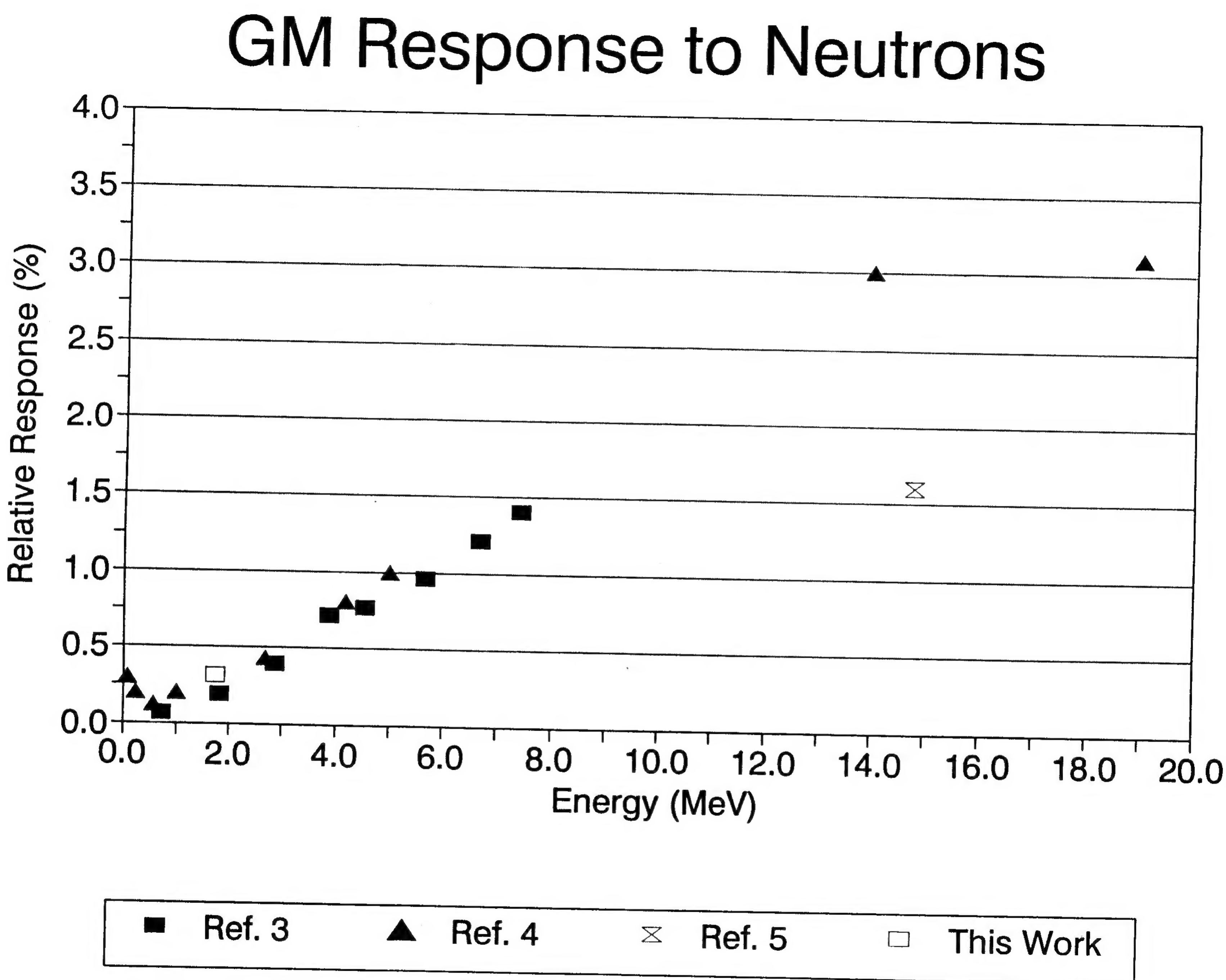

Figure 6. Geiger counter response to neutrons.

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